AIR EMISSIONS ACTION PLAN FOR CALIFORNIA DAIRIES

A report of the ad hoc Dairy Subcommittee of the
San Joaquin Valley Unified Air Pollution Control District

CONTENTS:

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Executive Summary

Home to the leading dairy region in the U.S., California also lays claim to regional air pollution that ranks among the nation's worst. How those distinctions relate concerns milk producers, air quality regulators, and environmental and public health advocates. This document suggests a plan of action for dairy air emissions research in California. This effort has a particular focus on the San Joaquin Valley, where this issue is most acute, but the plan is broad enough to apply to all regions of the state.

Despite significant regulatory efforts, San Joaquin Valley air quality has barely improved over the past two decades. Ambient levels of ozone and particulate matter (PM_{10}), both of which threaten public health, decreased only slightly. This may be viewed as limited progress, given that San Joaquin Valley population grew from 2.1 million people in 1981 to 3.2 million in 2000, while vehicle miles traveled grew from 35 million per day to 82 million per day during the same period.[1] However, health-based federal and state standards for both ozone and particulate matter are exceeded regularly in the San Joaquin Valley – standards for ozone are exceeded from 85 to 125 days each year, and particulate matter standards have been exceeded on as many as 180 days each year.[2]

Regional air quality still does not meet standards, and could worsen with continued growth and development. The federal Clean Air Act (CAA) requires air districts that failed to achieve ozone and PM_{10} standards, such as the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD), to submit implementation plans to achieve attainment of the standards within a specified period of time. If the plans are unable to identify sufficient reductions to achieve the standards by the deadlines, mandatory sanctions apply that will increase the cost of expanding or creating new businesses in the valley if they produce emissions. Sanctions also could result in a loss of billions in federal highway funds. As regulators undertake the daunting task of laying out a plan for better air quality, their big questions are: *Who is polluting? How much?* and *How can we reduce this air pollution to achieve the health standards?*

Dairies have come under scrutiny because of the industry's size and because dairy emissions can contribute to air pollution. Growth in the dairy industry has tracked growth trends in other sectors, with the total San Joaquin Valley herd increasing from about 477,000 milking cows in 1980 to nearly 1.3 million by 2003.[3] If dairies do play an important role in contributing to air pollution, the increasing size of the industry must be considered because:

- Cows and their manure produce organic gases, some of which react with other agents to form ozone. In the presence of ultraviolet light (sunlight), the Reactive Organic Gases (ROG) chemically interact with combustion byproducts such as oxides of nitrogen (NO_X) – from, for example, exhaust from gasoline or diesel engines – to form ozone. No one knows how much ROG dairy cattle produce and no reliable estimate of ROG for California dairies exists.
- Dairies contribute to formation of fine particulate matter ($PM_{2.5}$). Cows emit ammonia in urine and decomposing manure; this ammonia reacts with nitric acid compounds in the atmosphere to form very fine particles

[1] Air Resources Board 2002 Almanac, Chapter 4: Air Basin Trends and Forecasts (p. 161)
[2] Ibid., pps. 165 and 168
[3] California Department of Food and Agriculture, California Agricultural Statistics Service. http://www.nass.usda.gov/ca/

of ammonium nitrate. Understanding and quantifying how much ammonia dairy cows produce, and how much this contributes to particle formation in the atmosphere, is a critical research need.

- Cows walking on dry soil and manure can kick up dust, directly emitting some fraction of respirable particulate matter (PM_{10}). Current estimates of just how much PM_{10} are uncertain, as they are based on dairy research performed in another state and compared with beef cattle feedlots, which are managed quite differently than dairies. Research on California dairy management systems under local climate is needed.

Existing information indicates that dairy air emissions research is merited, but that so far, the impact dairies have on regional air quality is unclear. Understanding and regulating livestock emissions is a broad national issue. Regulators and scientists agree that they are just beginning to address important questions related to measuring such emissions. Along with all other residents of the San Joaquin Valley, the dairy industry shares a long-term interest in air quality and wishes to be proactive and supportive of research efforts to answer the important questions outlined here.

If it is determined that dairies play a significant role in regional air pollution, the dairy industry must lead the way in developing management practices to accomplish needed reductions. This plan sets short-term research objectives toward meeting pressing regulatory needs, while outlining longer-term approaches to improving our understanding of dairy emissions, their real-world effects and, as needed, real-world solutions to protect public health.

In the short term, research needs include initial measurements of precursors to ozone from ambient air samples near representative California dairies, and a survey to determine current management practices for typical dairy operations. To support these research efforts, additional cooperation between regulators, researchers and the dairy industry is needed. In addition, simple, cost-effective management practices should be identified and then promoted through the farm Conservation Management Practices (CMPs) program under development.

Mid-term research involves intensive data collection using both whole-farm studies and process-specific experiments to better quantify variability in emissions, and to begin to identify opportunities for reducing impact on air quality.

Long-term research should focus on developing high-quality modeling that can be used to better estimate on-site and regional emissions, and on developing effective, low-cost emission reduction strategies. Successful pollution reduction techniques will also require broad support so they can be standardized, commercialized and incentivized for wide introduction.

Short-term research objectives outlined here can be accomplished within 18 to 24 months; longer-term work can be advanced significantly within 3 to 5 years. Funding needs for five years of focused research are estimated at $2.4 million, with nearly $675,000 already secured.

Additional work may be needed beyond the scope of these recommendations; it is not possible to anticipate all future costs and research needs in this document. This plan proposes a general strategy for addressing needed research. This should become an iterative process where results of early research can be used to determine later objectives. To oversee the ongoing development of this action plan, we propose that an oversight group be formed to maintain an updated “working” research plan, seek needed funding for research, disseminate results and information, and foster ongoing cooperation between regulators, researchers and industry.

This committee recommends that the research objectives outlined here be fully funded, pursued aggressively, and executed with due haste and diligence. Doing so benefits both the public and the dairy industry, ensuring that dollars invested in improving air quality generate real, measurable benefits.

To connect research findings to action, this committee proposes development of a voluntary, market-based incentive program, built on the foundation of the California Dairy Quality Assurance Program, to train producers and assist them in compliance with air quality objectives. Such a program should include access to federal EQIP funds, while considering emission reduction credits for dairy producers and other types of incentives.

I. Background

Public health and regulatory status

Air emission research related to the dairy industry is primarily driven by public health concerns. Two health-related criteria pollutants are linked to dairies: ozone and particulate matter. Both pollutants are regulated under the federal Clean Air Act (CAA), and National Ambient Air Quality Standards (NAAQS). Dairies produce these pollutants directly (PM_{10}/dust) or contribute to their formation through release of precursors such as ammonia and reactive organic gases (ROG).

To comply with the CAA, air districts must develop reduction plans that address the emissions that are present in the region in order to bring air quality in compliance with the NAAQS. For example, the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) has not been able to reduce air pollution below federal standards for ozone and particulate matter. Because of this, the district must review all potentially large sources of pollutants to determine whether they are significant and can be controlled. While dairies emit some constituents of air pollution, the amounts are not well understood and methods of control have not been investigated. The trend of increased dairy herd in the San Joaquin Valley (growth of about 168% in the past 23 years)[4] heightens the importance of understanding the role of dairies in this public health problem. Research is needed to clearly evaluate the contribution of dairies to regional levels of ozone and particulate matter.

The San Joaquin Valley has been designated as a “severe” non-attainment area for the NAAQS one-hour standard for ozone. Under the requirements of the Act, the SJVUAPCD was required to submit a plan to reduce the levels of ozone in the valley, called a Severe Area Ozone Attainment Demonstration Plan, by May 31, 2002. That plan was supposed to outline how the district would achieve ambient ozone levels below the federal one-hour standard by November 15, 2005. While the district was able to submit a Rate of Progress plan, it was not able to demonstrate that a plan to reduce ozone levels by the 2005 deadline; as a result, a federal “sanctions clock” was activated, which could trigger severe regulatory penalties within 18 months if the district fails to correct the situation. Because of these pending sanctions, the air district is considering a plan to extend the attainment deadline by requesting that the district be re-designated as

[4] Source: California Department of Food and Agriculture. California Agricultural Statistics Service. http://www.nass.usda.gov/ca/

being in “extreme” nonattainment. Consideration of the status change is expected to be complete by September 2003. If the district does re-designate, it would have until early 2004 to submit a plan for attainment. Actual attainment-of-standards deadlines would also be extended, to 2010.

The San Joaquin is also in “serious” non-attainment for the NAAQS standard for PM_{10}. In mid-May 2003, SJVUAPCD issued a draft plan to attain the standard. The plan calls for further study of ammonia emissions from dairies to support future reduction strategies, and also recommends conservation management practices for dairies to reduce fugitive dusts. The plan indicates that research is needed to confirm reductions from current management practices and to develop new reduction strategies. The plan must demonstrate a 5 percent reduction per year in PM_{10} or PM_{10} precursors, and must be adopted no later than August 2003 to avoid regulatory penalties.

Regulatory penalties

Two types of penalties can occur for failing to meet requirements of the CAA. The first can be described as planning sanctions, and the second apply to actual attainment of the air quality standards.

Failing to meet the planning requirements results in imposition of CAA sanctions. For example, if the SJVUAPCD fails to submit a plan on time or fails to implement a control measure listed in the plan, after formal notice in the Federal Register, the U.S. Environmental Protection Agency (USEPA) starts a sanctions clock. If the deficiency has not been corrected within 18 months, the first sanction, 2-to-1 offsets on new and modified stationary sources, is imposed (that is, new or modified stationary sources, such as factories, must obtain pollution credits for twice the amount of pollutants the new facility will generate). Six months after the first sanction, a second sanction – withholding federal highway funds – is imposed. This puts $2.2 billion in funding for California at risk. Concurrent with the second sanction, USEPA is required to place the district under a Federal Implementation Plan (FIP) designed to meet NAAQS standards for ozone and PM_{10}.

As for actual attainment deadlines, if the SJVUAPCD fails to meet the current 2005 deadline for attainment of ozone standards, a $5,000 per ton emission fee would be imposed on major stationary sources within the district. This would cost San Joaquin Valley businesses as much as $30 million per year. A re-designation of the Valley to “extreme” nonattainment would delay the attainment deadline (and $5,000-per-ton fees) to 2010. However, re-designation would also trigger a more stringent set of permitting requirements for new and modified stationary sources, resulting in increased maintenance and development costs for industries, and potentially discouraging location of business entities in the San Joaquin Valley.

What do these regulatory pressures mean for dairies?

Two aspects of the federal planning requirements have increased attention on California dairies. First, the CAA requires that air districts develop an inventory of all pollution sources in the valley. Second, the CAA further calls for the SJVUAPCD to implement all feasible measures needed to reduce pollution from major sources enough to meet the NAAQS standards.

To meet the CAA’s requirements, the California Air Resources Board (CARB) and the SJVUAPCD develop and maintain an inventory of pollution sources for the San Joaquin Air Basin. Dairies and other farm emission inventory source categories are the responsibility of CARB. In performing an inventory update, CARB noted that dairies appeared to be potentially significant sources of primary emissions that play a role in formation of secondary pollutants. Specifically, initial CARB inventories indicate that dairies may be a major source of ROG, a precursor in the formation of ozone. Also, CARB inventories suggested dairies were a major source of ammonia, a precursor in the formation of secondary particulate matter. Finally, recent inventory work suggested that dairies might also be a significant source of PM_{10} through emissions of fugitive dust.

The SJVUAPCD concurrently is responsible for developing pollution reduction strategies for major stationary sources, toward meeting the NAAQS for ozone and particulate matter. Having already imposed regulations on other identified sources and drawing the conclusion that dairies were one of the largest remaining unregulated sources, the SJVUAPCD began investigating whether pollution-reduction strategies for dairies would be required for the district to meet its CAA requirements. In the course of this investigation, it was determined that current inventories of dairy air emissions lack sufficient basis. In particular, the ROG emission estimate was found to be based on outdated and incomplete data. Better inventories must be developed to support regulation and/or reduction strategies. The reasons for this determination are discussed in Section II.

Additional regulatory pressures

While implementation of federal requirements to achieve NAAQS standards represents the chief regulatory driver behind the need for additional dairy livestock air emissions research, additional considerations should be noted.

Under a recent court settlement involving the U.S. Environmental Protection Agency and environmental groups, air districts in California are now required to implement federal air pollution permitting programs (called Title V permits) for agricultural operations that are also major stationary sources of pollution. However, there is limited science related to emissions from dairies. That has made the process of determining which dairies are “major sources” – and thus subject to federal permits – difficult and uncertain. Additional research-based information will not only aid regulators now in determining which operations should apply for permits, but could help better refine those determinations in the future. Research could also determine techniques and technologies for reducing emissions below the levels at which a permit is required – thus realizing benefits for air pollution, regulators and the dairy industry.

California’s local governments, and not just within the San Joaquin Valley, also urgently need information related to dairy livestock air emissions. Analysis and quantification of these emissions is required to comply with the California Environmental Quality Act (CEQA) as local governments consider animal confinement ordinances. CEQA review is also triggered in some areas when local governments consider permits for construction of new dairies, or significant modification of existing dairies. These local governments look to federal, state and local air quality regulators for leadership in understanding cumulative, regional and local air quality impacts of livestock operations. Better data is needed to assist local government officials as they make long-term planning decisions and try to balance economic development and sound environmental management.

Scientifically sound research can provide county planners with tools to make appropriate local land use planning and other local regulatory decisions toward improving the public health and the economic well-being of their communities. In turn, informed local policy decisions support the efforts of state and federal air quality regulators to meet air quality objectives. For example, if counties require mitigation strategies for new dairies that don’t result in reduced emissions, no one gains – dairy producers invest in techniques and infrastructure that provide no benefits, while the public is denied any air quality benefit, and regulators are left still trying to meet air quality standards. But science-based mitigation strategies and planning policies help everyone involved.

II. Current state of science

This committee worked with cooperating scientists to conduct a literature review to determine what is known about livestock air emissions, particularly related to California-style dairy operations and the climate, topography and atmospheric conditions in which they operate. The committee was fortunate to have the benefit of concurrent work being done on a macro scale by the National Research Council's Committee on Air Emissions from Animal Feeding Operations. The NRC interim (2002) and final (2003) reports, "The Scientific Basis for Estimating Emissions from Animal Feeding Operations" were used to help develop the research approaches described in this document.

Background

Evidence in scientific literature indicates that livestock produce various emissions that can impact air quality. These include ammonia, hydrogen sulfide, reactive organic gases (also known as volatile organic compounds), and particulate matter. The literature review also encompassed other types of emissions from dairies.[5] For the purposes of addressing the regulatory pressures defined above, **reactive organic gases, ammonia,** and **particulate matter** are of most importance. We discuss these briefly below:

1) **Reactive Organic Gases** – ROG is a precursor to formation of ozone, and livestock operations are a potentially large source of ROG. ROG emissions from California dairies are not documented in the literature. Current emission estimates for ROG are based on a study of methane emissions from livestock that did not include speciation of ROG. However, it is widely accepted that ROG is a common component of livestock waste emissions. The NRC (2002) interim report stated that no standard methodologies exist for measuring emissions like ROG and that researchers are at the beginning of learning how to accurately quantify these emissions. Due to a lack of measurements of ROG on dairies, the significance of the dairy industry's ROG emissions in the San Joaquin Valley is unclear. However, given the industry's size, it is likely dairies may produce significant amounts of ROG on a regional level. We consider it imperative to study ROG emissions on dairies to arrive at accurate emission estimates and to replace the currently used ROG inventory data with research-based estimates.

2) **Ammonia** – Ammonia is a precursor to formation of particulate matter smaller than 2.5 microns ($PM_{2.5}$). The literature provides data on ammonia, but notes a significant lack of confidence of the reliability of existing emission factors. Existing measurements performed in California are based on very limited data that do not fully account for variations in geography, daily and seasonal weather differences, variations in dairy design and operation, variations in feed management, retention pond management and other critical factors. Without an adequate experimental design, an accurate emission factor cannot be developed because of the failure to account for the cyclical nature of the emissions. This is confirmed in the NRC (2002) interim report, which states: *"averaging published emission factors does not compensate for*

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[5] See Appendix for references and a discussion of additional livestock air emissions.

the presence of systematic bias that may be present as a result of a failure of the experimental design to account adequately for the cycles."

3) **Particulate Matter** – The impact of dairies on regional PM_{10} emissions is expected to fall into two categories: primary emissions (respirable PM_{10} from dust) and secondary particle formation (compounds formed by ammonia reacting with other chemicals in the atmosphere, typically forming particles smaller than 2.5 microns). Secondary emissions of ammonia are discussed above, but additional work describing how ammonia emitted from dairies contributes to particulate formation in the air basin is needed. With regard to primary emissions, there is very limited air emission data available for dairy operations in the United States. Because management practices and climate play an important role in determining these emissions, data gathered at representative California dairies is needed to determine useful emission rates.

An in-depth literature review related to dairy emissions is included in the appendices to this document. The most significant findings in this review dealt with what is *not* known about air emissions from dairies. We found little or no information in the literature to address the following questions:

- What are accepted standardized methods for measuring concentrations of reactive organic gases, ammonia and primary PM_{10} from dairies?
- How do emissions of ROG, ammonia and PM_{10} vary among different locations and processes on the dairy (direct animal emissions, retention ponds, corrals, application of manure to crops)?
- How does weather affect emissions?
- How to ROG emissions from dairies relate to elevated ozone levels in the valley? Do reductions in ROG emissions from dairies result in reductions of ground-level ozone?
- How do ammonia emissions from dairies relate to elevated particulate matter levels in the valley? Do reductions in ammonia emissions from dairies result in reductions of particulate matter formation?
- What mitigation measures are proven to be most effective? How do they relate in effectiveness to one another? Do any produce negative "side effects," such as impacting water quality or increasing emissions of other air pollutants?
- How much do other components of dairy operations, such as crops, offset overall air emissions from animals? Does a holistic look at dairy operations suggest overall benefits or detriments to ozone or particulate matter levels?

The current scientific literature is insufficient to determine accurate emission estimates for the San Joaquin Valley; it is also insufficient for determining mitigation strategies. This committee would advise caution against drawing conclusions about dairy impacts on air quality without first developing an accurate understanding and quantification of emissions representative of California dairies. The research plan outlined in Section III was devised to address the need for better dairy emissions information and provide a foundation to develop solutions where needed.

Dairy production in California

The overall size of the dairy industry in California air basins is important for estimating the impact on regional emissions. While milk production numbers or herd size alone is not enough to estimate emissions accurately, it does provide a basis for quantification. The dairy industry provides data annually to the Agriculture Statistics branch of the California Department of Food and Agriculture. This data on milk production is used to estimate the number of animals on a regional basis and is published annually in the CDFA Resource Directory. The population estimates for 2001 are 1.56 million producing cows in the State with nearly 253,000 in the South Coast region, 658,000 in the Southern San Joaquin Valley, 514,000 in the Northern San Joaquin Valley and 45,000 in the Sacramento Valley. This data is currently used by regional air modelers to inventory dairy emissions combined with per animal emissions factors.

Another important consideration for developing information on dairy emissions is to consider how dairying is practiced in California. Dairies employ various methods and technologies for feeding, animal housing and waste management, and it is likely that different methods will yield different emissions profiles.

Many types of feed are used in California in addition to feed grown on the dairy site, and the industry takes advantage of its proximity to byproducts of specialty crop and food processing to supply part of its rations. Feed may be wet or dry and may require milling or mixing before being rationed to animals.

Animals are typically housed either in drylots or freestalls with a separate milking barn on the dairy site. In drylot systems, animals are provided an open lot typically with a shade structure that often covers the feedlanes. Freestalls have paved lanes and are generally contained in a roofed barn with open sides and may provide a drylot for animal lounging during dry weather. Typically drylots are scraped periodically and manure is stored and utilized as dry solids. Some feedlanes in drylot systems are flushed to a lagoon system while others are scraped like the drylot. The lanes of most freestall systems are automatically flushed with recycle water 2 – 5 times a day to remove manure to a waste handling system. Milking barns are typically cleaned with fresh water. Manure water often goes through some type of solids separation process and the solids are often reused for animal bedding. The remaining liquid flows to a lagoon where it is stored until it can be properly applied to cropland.

Some important observations about the California industry include that diets are likely to be more varied than other regions, animals are typically housed in the open (with roofs for shading or rain protection), and the amount of manure handled dry or wet will depend highly on the extent to which flushing systems are employed. The extent of each practice is not well documented but the general trend is towards freestall dairies with flush systems and solids separation. There are regional differences based on the age of the dairies, availability of water and other factors.

III. California dairy air emissions research plan

Objectives

This committee recommends a dairy research plan to study air emissions and their mitigation. This plan has short-, mid- and long-term goals, which will be refined over time.

The overall objectives of this research plan are:

1. To develop high quality emission estimates for dairy operations, and to develop a dairy emission model to predict temporally resolved, farm- and farm process specific emissions for dairies;
2. To evaluate and compare air emission mitigation techniques and technologies for dairy operations.

All objectives will address reactive organic gas, ammonia, and particulate matter emissions from dairy farms and their processes. Objectives will be addressed in a combination of whole-farm studies, process-based research, and modeling effort (see below).

Research plan

This plan sets short-term research objectives toward meeting pressing regulatory needs in finding emission estimates, while outlining mid- and longer-term approaches to improving our understanding of dairy air emissions, and emission mitigation.

- Emission estimates

Short-term:	Perform whole-farm measurements of ROG (Appendix A). Perform surveys of current management practices,
Mid-term:	Conduct process-level experiments of all constituents, Perform whole-farm measurements of all constituents.
Long-term:	Incorporate process-level data into models, Use on-farm measurements to test models.

- Emission mitigation techniques and technologies

Short-term:	Perform surveys of current management practices, Develop linkages between producer groups and agencies.
Mid-term:	Test and compare air emission mitigation techniques and technologies at process-level.
Long-term:	Perform on-farm testing to confirm expected benefits, Quantify pollution reductions and costs associated with mitigation techniques and technologies.

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Research approach

The dairy industry in California is typified by a great variety in operational characteristics and potential air emissions. Variability in air emissions within and among dairies is due to a number of factors, including but not limited to animal housing, animal type, feeding and nutrient input, animal productivity, manure storage and handling, soil type, and climate. This variability makes it challenging to arrive at representative data (e.g., emission factors) for the entire industry. However, to arrive at representative emissions estimates, we suggest combination of three research approaches: 1) the whole-farm approach, 2) the process-based approach, and 3) modeling approach. These three research approaches are complementary and take into account the complex nature of the issues at hand, dairy farm emissions and their mitigation.

1) In recent years, numerous researchers used a methodology to estimate air emissions from Animal Feeding Operations (AFOs) that this document refers to as the **whole-farm approach**. Research groups have applied various methods to measure emissions from unenclosed AFO. These methods included wind tunnels, chambers, vertical profiling, and dispersion modeling, all based on measurements of concentration. These descriptive studies have been conducted for ammonia and PM, but have yet to be done for ROG.

   Use of the whole farm approach, requiring *in situ* measurement of air constituents under actual field conditions, has the advantage of providing information about the real-world situation on the particular farm. However, measuring emissions from a whole farm can be biased and confounded by changes in wind direction, spatial variability in emissions within the dairy, proximity to other pollution sources, etc. Some of these variables can be normalized with instrumentation and experimental setup (see example project, Appendix A).

   Arriving at representative annual emission estimates for the dairy industry by means of emission factors requires that measurements be made over the full range of dairy operating conditions. To account for the variability in the dairy industry and to establish comprehensive and accurate annual emission factors using the whole farm approach alone would require measurements at a large numbers of operations, which can be costly and infeasible (NRC 2002).

2) The **process-based approach** takes into account that a dairy is a heterogeneous operation consisting of freestalls, drylot pens, milking parlor, and retention pond, each of which may each contribute to facility emissions. Processes within the dairy are animal feeding, management, housing, as well as manure handling and treatment. All of these processes have their individual air emission profile and can be investigated separately as long as the movement and transfer of products is accounted for throughout the system.

   The most relevant air constituents emitted from dairies – reactive organic gases, ammonia, and particulate matter – are associated with certain dairy farm processes (Table 3). For example, it is widely accepted that particulate matter from dairies is primarily emitted from drylot pens by cow activity (PM mainly being dried pulverized manure and soil particles kicked up by cows' hoof action). PM is typically not associated with manure management facilities like the lagoon, or concrete floored housing facilities like freestalls. Another example for process specific air emissions is ammonia. The main source for ammonia is urea from urine excretions of cows. Ammonia is mainly volatilized from drylot pens (during the drying of the animal's excreta) and manure handling facilities. Therefore, ammonia research should focus on the animals in their housing system (especially drylot pens) and the manure handling system. Finally, only limited information is available regarding ROG emissions, but it can be assumed that these emissions are generated during enteric fermentation within the animal and during the breakdown of manure.

TABLE 3. Process factors that may impact the emission rates of various pollutants are identified along with the sources for the pollutants. For illustration, the right column gives an example of how the italicized factor can impact emission rate.

Pollutant	**Sources**	**Process factors**	**Example**
Reactive Organic Gases	Enteric fermentation Manure solids fermentation	Feed composition *Solids content of manure* Waste management Loading rate Retention time Climatic conditions	Generation of volatile organics by fermentation is optimized under certain solids concentrations
Ammonia	Urea from animal excretion	Nitrogen content of feed Ground moisture *Cleaning schedule* Waste management Climatic conditions	Freestall flushing reduces ammonia volatilization
Particulate Matter	Dust generating animal activity	*Type of housing* Animal schedule Cleaning schedule Ground moisture Climatic conditions	Animals may generate more dust from drylot pens than from concrete floored freestalls

The process-based approach investigates dynamic processes creating each of the constituents (ROG, ammonia, and PM) and the sources of the airborne products. It involves conducting controlled experiments to determine the impact of process and environmental factors on emission rates. This knowledge is needed to be able to predict emissions and determine the efficacy of mitigation measures. Because the process-based approach is generally applied in a research facility, not on a production dairy, careful attention must be paid to assumptions and scaling of results. Ultimately process-based results must be verified with field measurements.

3) Results from process-based emissions research will be incorporated into a **dairy emission model** to estimate temporally resolved, farm- and farm process specific emissions for dairies. The model should account for how emissions vary as a function of livestock population characteristics (total number of animals, type, age), husbandry practices (diet, building design, waste management practices), and local environmental conditions (ambient temperature, rainfall, humidity, soil types). In this final phase of the research plan, whole-farm measurement methodology will be used to confirm emissions forecast by process-based research and modeling.

All research efforts interact to generate higher quality emissions estimates and improved management practices and technologies (Figure 1). Both process-based research and whole-farm studies require careful attention to environmental factors that could impact emissions. These two methodologies provide complementary ways to arrive at emissions estimates through modeling giving the ability to corroborate results. Research also provides a better understanding of how management practices and mitigation measures impact facility emissions.

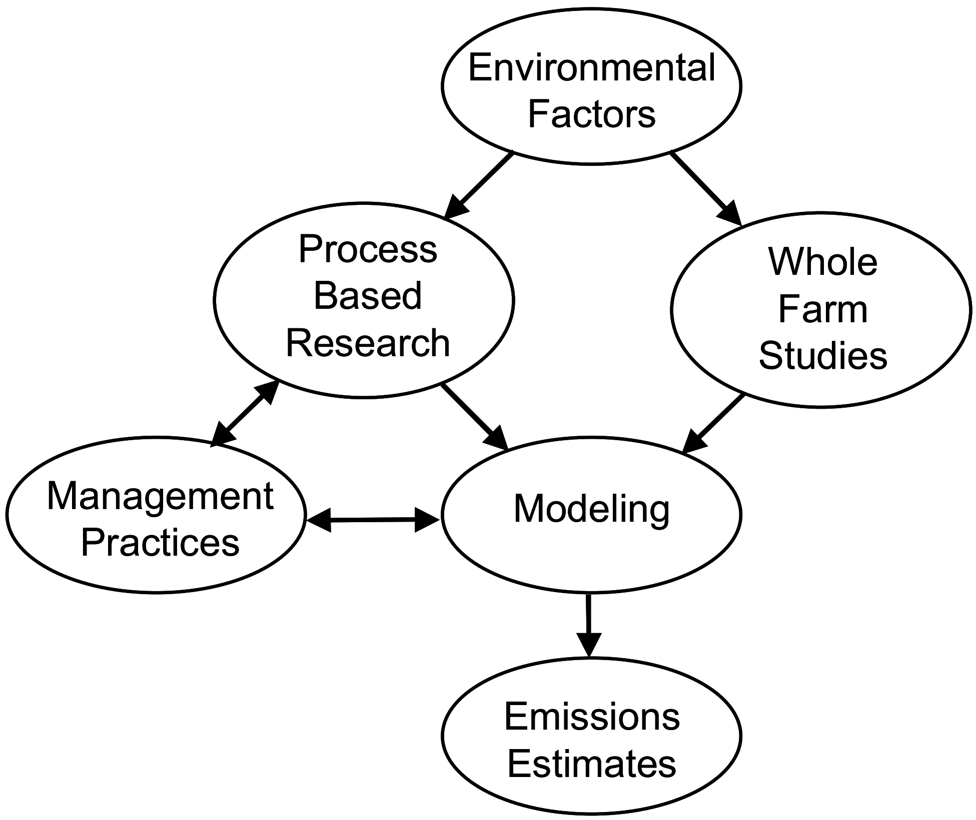

Figure 1. Interrelationship among process-based and whole farm approach and modeling to arrive at accurate emission estimates and management practices that can mitigate emissions.

Budget and Timeline

This section is intended to describe costs and expected timeline for the initial portion of the program. Research efforts described here may not accomplish all of the goals and objectives outlined above, but will advance the work significantly for the pollutants of concern. Results of the work completed should be used to re-evaluate goals and objectives, plot needed course corrections, and develop additional research needs toward the goals outlined above.

This plan lays the groundwork for measuring and inventorying dairy emissions and for testing of pollution-reduction strategies that are identified during the process-based research or brought forth by outside proponents. Sufficient funding for a focused five-year research effort is proposed here, but future work may be needed for additional pollution reduction strategies. The cost estimates and general timetable for implementing the plan are presented in Table 4 and Table 5 and justification for the funds are discussed below.

Short-term work focuses on collecting and analyzing initial samples of ROG from a typical California dairy (see Appendix A), performing surveys of current management practices, and developing collaborative linkages between producers, researchers and industry. These efforts have been initiated in 2002. The cost of these short-term efforts is $150,000.

Mid-term efforts are where the bulk of the field and research work will take place and, accordingly, has the highest cost at $1,900,000. These efforts should commence with significant data collection in 2003 and should continue intensively for three years with additional work beyond that as needed. Process-level research should involve a series of experiments looking at the factors discussed in the research approach. A proposed budget contains funding for 10 to 14 extensive process-based research experiments that should feed the long-term model development needs. Whole-farm studies should continue from the initial ROG work along with refinement of field instrumentation and methodology. Sufficient funds are included to perform studies of ROG, ammonia and PM on at least 6 dairies. This does not include the cost of equipment to speciate ROG, which should be shared among all efforts in this category. Specific novel technologies to mitigate emissions may be brought forward by the air and waste management industry or by researchers. Funding to perform controlled testing on 3 to 5 technologies is included in the mid-term efforts. This assumes that the technology proponent will provide the equipment at low or no cost for testing.

Long-term efforts are focused on consolidating data, developing models and quantifying potential benefits and costs of mitigation techniques and technologies. It is expected that data from the mid-term efforts feed into these efforts and that they feed back to mid-term activities. Therefore, preliminary models should begin to be developed after the first year of data collection from the field and from experiments. Whole-farm measurements should be compared with process-based modeling results as soon as data are available to determine weaknesses and develop future research needs. Quantifying the emission reduction benefits of mitigation techniques is not shown as a large cost here because it is expected that the Air Resources Board and regional air districts would be responsible for this analysis. It is difficult to quantify a precise cost for all of these long-term efforts as some will be ongoing, but to develop high quality tools for estimating emissions that will be useful for decision making, it will require at least $400,000 during the five-year course of this research.

TABLE 4. Dairy research plan costs and funding needs

	Time needed	*Cost ($1000)*	*Funding ($1000)*
Short-Term Objectives			
Perform initial whole-farm measurements of ROG	Fall '02	30	30 [1,2]
Perform surveys of current management practices	Fall '02	20	20 [4]
Develop linkages between producer groups and agencies	Fall '02	100	100 [6]
Subtotal		*150*	*150*
Mid-Term Objectives			
Conduct process-level experiments of all constituents	Spr '03	1,200	775 [3,4,5]
Perform whole-farm measurements of all constituents	Spr '03	400	350 [1,2,3]
Test emission mitigation techniques and technologies	Spr '04	300	0
Subtotal		*1,900*	*1,125*
Long-Term Objectives			
Incorporate process-level data into models	Spr '04	150	0
Use on-farm measurements to test models	Spr '05	100	0
Perform on-farm testing to confirm expected benefits	Spr '05	100	0
Quantify pollution reductions from mitigation	Spr '05	50	0
Subtotal		*400*	*0*

Total Costs	*2,450*
Funding Secured	*675*
Funding Tentative	*600*
Additional Funding Needed	*1,175*

Funding Sources

1. Air Resources Board ($100k secured)
2. Dairy Industry ($40k secured)
3. United States Department of Agriculture ($375k secured)
4. University of California ($80k secured)
5. Merced County/SWRCB ($600k pending)
6. All Members of Subcommittee ($100k secured)

TABLE 5. Suggested timetable for characterization of livestock air emissions

Research Category	Cost ($1000)	2002	2003	2004	2005	2006	2007
Emission estimates							
Perform whole-farm measurements of ROG	30	High Effort	Low Effort	Low Effort	Low Effort	Low Effort	Low Effort
Conduct process-level experiments	1,200	Medium Effort	High Effort	High Effort	High Effort	Medium Effort	Low Effort
Perform whole-farm measurements	400	Medium Effort	High Effort	High Effort	Medium Effort	Medium Effort	Low Effort
Incorporate process-level data into models	150	Low Effort	Medium Effort	High Effort	High Effort	High Effort	Medium Effort
Use on-farm measurements to test models	100	Low Effort	Medium Effort	High Effort	High Effort	High Effort	High Effort
Emission mitigation techniques and technologies							
Perform surveys of current practices	20	High Effort	High Effort	Low Effort	Low Effort	Low Effort	Low Effort
Develop linkages between groups and agencies	100	High Effort	High Effort	Medium Effort	Medium Effort	Medium Effort	Medium Effort
Test and compare air emission mitigation	300	Low Effort	Medium Effort	High Effort	High Effort	High Effort	Medium Effort
Perform on-farm testing to confirm benefits	100	Low Effort	Low Effort	Medium Effort	High Effort	High Effort	High Effort
Quantify pollution reductions from mitigation	50	Low Effort	Low Effort	Medium Effort	High Effort	High Effort	High Effort

Legend: Low Effort; Medium Effort; High Effort

Note: Methodology development is a part of all efforts listed above

Research management and funding

Research funding dedicated to dairy air quality issues has been identified by the Dairy Subcommittee. An estimated $575,000 (plus an additional $100,000 in-kind support) has been secured by research groups from Fresno State, UC Davis and Texas A&M, and will be put into action soon. The proposed budget (Table 4) details what areas this funding will be applied to and the source of the funding. Research funding by Merced County of $600,000 for process-based research and mitigation techniques and technologies is pending approval. An additional $1,175,000 will be needed over the next three years to fund the efforts outlined in this plan.

In order to coordinate research efforts and insure the execution of this plan, it is recommended that an oversight committee be assembled with academic, regulatory and industry representatives. The role of this group will be to insure that research efforts are coordinated to address the objectives of this plan. Specific tasks for this committee would be:

1. *Maintain a "working" research plan.* The plan should be updated based on incoming research results and additional needs that are identified. Identifying where additional research is needed will be an ongoing effort.
2. *Seek additional funding for research.* This may entail the development of funding for a specific RFP associated with this plan. It could also involve providing letters of support for funding and individual proposals that address key areas of the plan.

3. *Provide results and information*. This committee should be a resource for the latest information on dairy air quality. This information should be in a format that is easy to understand and use. It is recommended that data from studies be made available to all interested parties, possibly by the use of a technical website.
4. *Foster ongoing cooperation*. Continued collaboration of regulators, researchers and industry will be vital. It is expected that this committee would participate by helping researchers find cooperating dairies, discussing and disseminating research results, informing industry of air quality regulatory schedules, and developing incentive-based programs.

IV. Sustainable incentive-based programs

For research to translate to action, a plan will be needed to ensure wide-scale adoption of those measures deemed feasible for reducing air emissions from dairies. This committee suggests that an educational curriculum and a voluntary, incentive-based program will go far toward accomplishing that goal.

A fully developed program is not present at this time, partly because of the relative infancy of understanding of livestock air quality issues and potential control measures. However, such a program will be needed and we recommend that government, the scientific community and the dairy industry continue working together to develop such a voluntary, market-based incentive program. Elements of such a program should be built on the foundation of already successful programs and concepts, including: educating producers on air quality management in the California Dairy Quality Assurance Program, funding environmental improvements from Federal programs like Environmental Quality Incentives Program and the Conservation Reserve Program, developing programs to generate Emissions Reduction Credits for mitigation measures, and utilizing other state and federal incentives to encourage novel mitigation measures.

Each of these options is discussed briefly below.

California Dairy Quality Assurance Program

The California Dairy Quality Assurance Program (CDQAP) is an unprecedented public-private partnership of state and federal regulatory agencies, universities and the dairy industry to encourage compliance with all applicable laws through education and certification of dairy producers. Dairy producer participation in the CDQAP is voluntary. It does not replace regulatory responsibilities or enforcement – rather, it helps producers to understand their responsibilities and to comply with them before regulatory action is needed. More than 1,000 California dairy producers have participated in various aspects of CDQAP and efforts are under way to further expand the program's reach and effectiveness.

To date, the program has focused on issues related to water quality, animal welfare and food and biosafety. Funding has been obtained to develop a component in the CDQAP to educate producers about air quality and the steps they can take to reduce emissions. When air emissions from dairy farms are better understood, a certification component to assure compliance with all applicable air quality laws and regulations will be possible. Because CDQAP is a well-developed entity, it makes sense to use this tool as a method of outreach, education and compliance certification for air quality mitigation measures.

Environmental Quality Incentives Program/ Conservation Reserve Program
The Congress each year allocates tens of millions of dollars toward environmental improvements, such as habitat conservation, erosion control and water quality protection, through the USDA-Natural Resources Conservation Service-administered Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Program (CRP). EQIP and CRP are both promising vehicles to partially fund capital improvements and offset the cost of operational changes in dairies to the degree that doing so would improve air quality by reducing overall livestock air emissions. Additional opportunities are available to utilize air quality improvement practices as dairy producers begin to implement Comprehensive Nutrient Management Plans under guidelines expected to be published later this year.

For and EQIP/CRP and similar funding approaches to be successful, researchers, NRCS technical experts and agricultural extension experts, working in concert with the dairy industry and regulators, must develop a menu of mitigation options, that is recognized management practices and technologies that have a quantifiable effect on emissions. Items on this options menu would be formally recognized as “fundable” under NRCS guidelines, opening up an important source of funding and incentives to address air quality issues. We recommend that a formal, coordinated effort be made to address these issues, possibly in the form of either a research oversight committee or through creation of a Natural Resources Conservation Service funding application subcommittee.

Emissions Reduction Credits
Emission Reduction Credits (ERCs) represent a real, quantifiable and bankable option for crediting dairy producers for their investments toward reducing any baseline emissions they are determined to produce. As they are for other industries, ERCs have been a useful tool to encourage innovation and pollution reduction in agriculture, particularly in regard to emissions from diesel engines and open-field burning. However, ERCs also are generally linked to permanent reductions in emissions and don't always adequately account for flexibility needed in agricultural operations. Geographic limitations and market considerations also apply - agriculturally generated ERCs should be marketable across a large area.

ERCs depend on the concept of developing a baseline historical emission profile for a particular dairy (or a standard dairy) and then documenting reductions through new management techniques. Dairy producers commit to permanent reductions and in return are granted bankable/saleable pollution offset credits proportionate to their reductions. In turn, these credits may be sold to other industries that are required to purchase such offset credits as a condition of their operating in a pollution-sensitive area.

Several barriers to implementation would need to be overcome to create a successful ERC program. First, the ERCs must be over and above any voluntary best management practice (BMP) program developed by the SJVAPCD or potential regulation arising from federal Title 5 permitting requirements unless the plan, rule, permit or requirement identifies an ERC mechanism as an incentive - which is recommended by the committee. Second, ERC's will need to be calculated on a quarterly basis; since emissions are expected to vary with operational and seasonal environmental conditions, the amount of reduction achieved would also vary at different times of the year. Third, the requirement for ERCs to be quantified and verified will require the ability to measure emissions at dairies at levels of accuracy that have not yet been achieved in practice but for which this research program may achieve. Therefore, it is critical that the region's attainment plan address flexible permit programs and incentives within prohibitory rules that allow for the generation of ERCs as an incentive.

Because of historical difficulties related to implementation of ERC programs, and the necessity of the market based approach in achieving emission reduction goals, it is crucial that developers of such a program work closely with the dairy industry.

Other incentives

To the degree that air quality mitigation measures developed for dairies require substantial capital investments or increased operating costs, incentives and programs to offset those costs are needed. These can include those previously described, plus low-interest loans, grants and tax incentives.

Such incentives can be direct to the dairy producer, offsetting costs for process improvements. A recent example of an incentive-based program is the $10 million California Energy Commission grant program administered by Western United Resource Development, Inc. that provides matching funds to producers who participate in a pilot program for building manure-to-methane digesters for on-farm energy production. Incentives should also be considered for indirect operations, such as tax incentives for dairy processors that provide programs for their producers. For example, Hilmar Cheese Co. has provided premium payments to encourage their producers to complete the California Dairy Quality Assurance Program.

VI. Appendix: Literature review and references

In preparing this Action Plan, the SJVUAPCD's ad hoc Dairy Subcommittee reviewed existing scientific literature related to dairy livestock air emissions, for the purposes of summarizing the current state of knowledge.

This appendix includes a more detailed discussion of individual air pollutants emitted by dairies, references to those pollutants in the literature and a listing of general references. One of the committee's primary resources were the recent reports of the Ad Hoc Committee on Air Emissions from Animal Feeding Operations of the National Research Council (NRC, 2002, NRC, 2003). Those reports address the emissions of ammonia (NH_3), volatile organic compounds (VOC), within this broad classification of organics there is ROG (reactive organic gases for formation of tropospheric ozone), the two particulate matter classes, $PM_{2.5}$ and $PM_{10,}$ nitric oxide (NO), nitrous oxide (N_2O), hydrogen sulfide (H_2S), methane (CH_4), and odors.

As described in Section I of the Action Plan, regulatory circumstances in the two largest air basins of California (the San Joaquin Valley and South Coast) compel a prioritization for research on reactive organic gasses, ammonia, and particulate matter. These are the compounds that are emitted from dairies with potential to impact regional ozone and particulate matter levels. As discussed in the NRC reports, other emissions from animal feeding operations may be of local concern (e.g. odors) or be of global concern (e.g. CH_4 and N_2O for their potential impact on global climate change). Interested readers should refer to the NRC reports for more details regarding these other emissions from animal feeding operations and their potential impacts.

The compounds of concern from a regional standpoint generally have short lifetimes of less than 1 day to 10 days in the ambient atmosphere. Reaction, deposition and precipitation processes work to remove them from the atmosphere. Also reactive organic gasses and ammonia must chemically interact with other compounds to create ozone or particulate matter impacts. The dynamics and chemistry of these processes can be affected by climate, topography, vegetation, surface soil, moisture and numerous other effects. Due to this complexity, these interactions require research and modeling to determine causal relationships with health concerns.

Reactive organic gases[6]

Reactive organic gases (ROG) are organic compounds (containing carbon) that exist as gases at ambient air temperatures and are reactive in the atmosphere in the formation of tropospheric ozone. There are more than 400 classes of gases in the ROG emission category. Some examples are fatty acids, nitrogen heterocycles, sulfides, amines, alcohols, aliphatic aldehydes, ethers, mercaptans, hydrocarbons and halocarbons.

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[6] For most purposes, ROG as defined by the State of California are substantially equivalent to the term Volatile Organic Compounds (VOCs) used in most scientific literature and in federal regulatory documents. Methane (CH4), one of the most common organic gases and also produced in large amounts during enteric digestion, is not considered to be reactive or an ozone precursor and thus is not defined as ROG by the state; however, federal definitions include methane as a VOC. The federal government occasionally uses the term Non-methane Volatile Organic Compounds (NMVOCs) to capture this distinction. For clarity and because ROG is the term used in the state emissions inventories that are of most direct concern here, the committee has chosen to refer to this class of gases as ROG throughout this document.

Several ROG can irritate eyes, nose, throat and skin upon contact. At high-concentration exposures they can be carcinogenic, cause nervous system disorders, or trigger cognitive emotional stress. However, the effects of ROG emissions from Animal Feeding Operations (AFOs) on public health are not fully understood or well studied (NRC, 2002).

Due to complex tropospheric transport in the SJV, ozone in the valley is formed from precursor chemicals that represent a mix of out-of-valley and in-valley sources (Dabdub et al., 1999). These precursors and co-reactants comprise a long list of volatile organic hydrocarbon (VOHC), nitrogen (VON), and sulfur (VOS) compounds, as well as inorganic forms of these elements such as ammonia. The chemistry of ozone formation is complex; for example, one SJV model used 29 of these constituents interacting with each other in 83 different reactions (Dabdub et al., 1999). It is presently understood that the identity of the specific chemical players are extremely important to determinations of the likelihood or rate of ozone formation, so that information on total VOHC, VON, or VOS is not very useful. Reaction rate constants for 85 organic compounds with OH radicals, the first step in tropospheric ozone formation, have been shown to vary over 4 orders of magnitude (Atkinson, 1987).

The VOC and inorganic nitrogen from rural, biogenic sources may sometimes exceed emissions from urban anthropogenic sources (Rappengluck et al., 1999). Rural biogenic sources can include microbial and algal activity (e.g., (Stahl and Parkin, 1996); (Fischer et al., 1999)) in soils and water. In particular, agricultural pond surface waters are considered major sources of VOC globally (e.g., (Nouchi et al., 1997)), such as emissions from rice fields (e.g., (Yang et al., 1998)).

Current dairy ROG emission estimates are derived from a study that measured methane, but which did not measure any other gas. This data was then used to estimate ROG assuming a relationship between ROG and methane. The NRC (2002) reports states: "methane does not provide an appropriate basis for predicting VOC volatilization potential in animal management systems. Gas transfer velocities for CH_4 and VOCs differ by several hundredfold (MacIntyre et al.,1995). In addition, surface exchange rates for some VOCs are influenced by solution-phase chemical factors that include ionization (pH), hydrogen bonding, and surface slicks (MacIntyre et al., 1995). Physical factors such as temperature, irradiance and wind are also major factors in the emission rates of sparingly soluble VOCs from liquid and semisolid surfaces (MacIntyre et al., 1995; Zahn et al., 1997)".

Ammonia

Dairy manure contains nitrogen that can form ammonia by a combination of mineralization, hydrolysis, and volatilization processes (Oenema et al., 2001). Gaseous ammonia reacts with atmospheric acidic substances to form the ammonium aerosol (NH_4^+) that in turn can contribute to formation of fine secondary particulate matter ($PM_{2.5}$). These fine particles can be deposited locally to contribute to acidification, fertilization and eutrophication (NRC 1997). Particulate ammonia has been shown to comprise as much as 27% of the total PM_{10} concentration in the SJV during the winter (Chow et al., 1992) and is also a significant concern in the South Coast air basin.

Air quality research focused on dairy production systems is very limited (Groot Koerkamp et al., 1998) and most studies that were conducted overseas cover different feeding operations, farm sizes, and manure management systems compared to those presently used in California. Ammonia emissions have been measured for mechanically ventilated animal houses (Smits et al., 1995; Ogink and Kroodsma, 1996; Braam et al., 1997), naturally ventilated animal houses (Demmers et al., 1998), and grazed fields (Misselbrook et al., 1998). But no published measurements of ammonia emission rates for open lot or freestall dairies of the type common in California are available.

Several research efforts have begun to focus on the factors that contribute to ammonia emissions. Ammonia studies with focus on temperature and moisture have been conducted for beef cattle (Hutchinson et al., 1982) and swine facilities (Aneja et al., 2000). Zhu et al. (2000) investigated diurnal variations of ammonia in buildings as a function of animal age and feeding. Amon et al. (1997) studied effects of manure handling in poultry and Hoeksma et al. (1982) in swine systems on ammonia emissions. Considering all the effects that impact air emissions, it is unreasonable to expect that short-time sampling (e.g., a few days) on one individual facility or a small number of facilities can represent the industry as a basis for emission factors.

Particulate Matter

National Ambient Air Quality Standards (NAAQS) exist for both PM_{10} and $PM_{2.5}$ (Table 2). PM_{10} refers to a class of particulates that are 10 microns in diameter or smaller and $PM_{2.5}$ to those that are 2.5 microns or smaller. The size of PM_{10} is commonly expressed as about the size of one-seventh the diameter of a human hair. This is the aerodynamic diameter, that is, the effective diameter of the aerosol in the atmosphere collected at 50 percent efficiency, using the Federal Reference Method samplers (FR, 1997). It is important to realize that any sample of $PM_{2.5}$ is a component sample of PM_{10}. PM_{10} emissions from a dairy could be from mechanical entrainment of mineral or organic components of the soil or manure pack. An example of a $PM_{2.5}$ emission could be ammonia that has converted to aerosols through chemical reactions in the atmosphere.

TABLE 2. National Ambient Air Quality Standards for particulate matter

Particle size	Standard in micrograms/meter^3	Averaging period
PM_{10}	50	1 year
	150	24 hours
$PM_{2.5}$	15	1 year
	65	24 hours

SOURCE: http://www.epa.gov/airs/criteria/html

Particulate matter research in cattle production systems was reported from beef feedlots by Parnell et al. (1994), and Grelinger (1998). Also, Hinz and Linke (1998) and Takai et al. (1998) reported emissions inside livestock buildings. Takai et al. (1998) conducted their extensive investigations in Northern Europe with little applicability to the large herds found in California. Very limited air emission data is available for dairy operations in the United States. The most recent dairy emission data were collected by Parnell et al.

[7] For most purposes, ROG as defined by the State of California are substantially equivalent to the term Volatile Organic Compounds (VOCs) used in most scientific literature and in federal regulatory documents. Methane (CH4), one of the most common organic gases and also produced in large amounts during enteric digestion, is not considered to be reactive or an ozone precursor and thus is not defined as ROG by the state; however, federal definitions include methane as a VOC. The federal government occasionally uses the term Non-methane Volatile Organic Compounds (NMVOCs) to capture this distinction. For clarity and because ROG is the term used in the state emissions inventories that are of most direct concern here, the committee has chosen to refer to this class of gases as ROG throughout this document.

(unpublished) at a Texas dairy (200 measurements at an 1,800-lactating cow operation). The PM_{10} emission concentration obtained for that dairy was 4 ± 3 lbs. for 1,000 cows per 24-hour period. However, these measurements were taken on one dairy and over a period of two weeks in the summer, so other seasonal variations were not measured. Diurnal variations were accounted for. Measurements were taken with a high volume total suspended particulate (TSP) sampler. PM_{10} concentration was obtained by multiplying .25 times the TSP concentration (Grelinger, 1998). A general protocol has not been accepted for dairy particulate measurements with limitations to the accuracy of Federal Reference Method PM_{10} samplers in a large-particle-rich environment (Buser, et al., 2002).

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